(51) International Patent Classification 3 : G01P 15/13	A1	(11) International Publication Number: WO 86/00416
		(43) International Publication Date: 16 January 1986 (16.01.86)

(54) Title: DIGITAL OUTPUT INSTRUMENTS
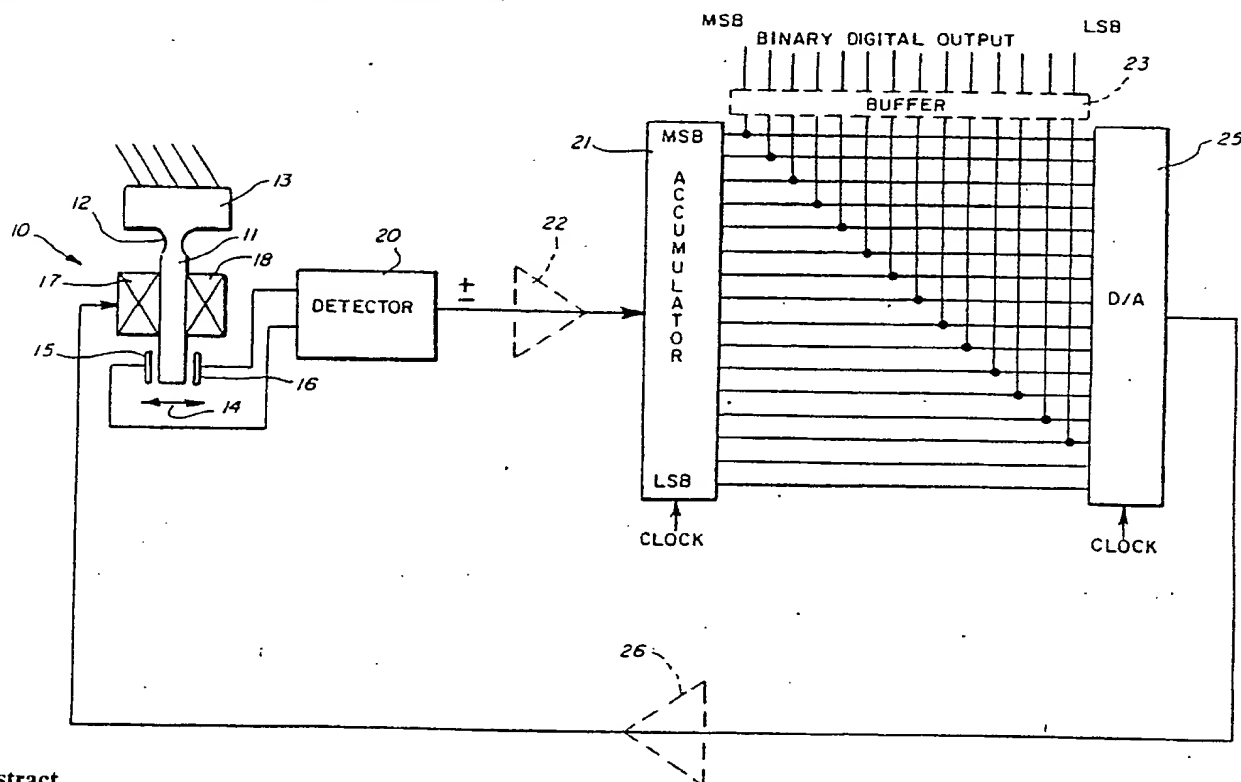
(57) Abstract

A servoed accelerometer (10) is connected with an accumulator (21) to provide a binary digital output. The accumulator output is connected with a digital-to-analog converter (25) which provided an analog rebalance signal to the accelerometer.

1

DIGITAL_OUTPUT_INSTRUMENT

Technical_Field

This invention relates to a measuring instrument, as
a servoed accelerometer, with a digital output.

05
Background_of_the_Invention

Typical accelerometers have an analog output of
current, voltage or frequency. In order to interface such
an instrument with a digital computer, the analog signal
must be converted to digital form. For the current and
10 voltage instruments, this is generally accomplished with
an analog-to-frequency converter. In the case of a fre-
quency output accelerometer or a voltage-to-frequency
conversion, a computer or other frequency measurement is
required to generate a digital output. In an open loop
15 configuration, such an instrument is nonlinear. In a
closed loop instrument, the output has a high noise level
and different scale factors for positive and negative
inputs.

Summary_of_the_Invention

20
In accordance with the present invention, a servoed
instrument has a displaceable element with means for
applying force to the element to return the element to its
null position. A detector responsive to displacement of
the element from the null position has an analog output
25 signal with a polarity which indicates the direction of
displacement and an amplitude which represents the

magnitude of the displacement. An analog-to-digital
converter is responsive to the detector output signal and
has a digital output representing the sensed stimulus to
which the element responds. A digital-to-analog converter
05   has an input connected with the output of the analog-to-
digital converter and an analog output connected with the
displacement element forcer to return the element to the
null position. The digital output of the analog-to-
digital converter provides an instrument output which is
10   computer compatible.

More particularly, the analog-to-digital converter
is an accumulator, the output of which is one-half full
count for a null condition in the absence of a stimulus
acting on the displacement element and which increments
15   for one polarity of detector output signal and decrements
for the opposite polarity of detector output signal.

Another feature of the invention is that the
digital-to-analog converter has a bipolar analog output
which is zero for one-half full scale digital input.

20   Further features and advantages of the invention
will readily be apparent from the following specification
and from the drawing which is a schematic representation
of a servoed accelerometer and a digital output circuit
illustrating the invention.

25   The invention is illustrated and will be described
as incorporated in a force rebalance or servoed
accelerometer. Various aspects of the invention may be
used with other digital instruments having an element
displaceable from a null position in response to a sensed
30   stimulus. The claims should not be considered limited to
an accelerometer or to other details of the disclosure
unless expressly so stated.

Accelerometer 10 has a proof mass element 11
connected by a hinge section 12 with a base 13. Proof
35   mass 11 is displaceable in opposite directions from its
null or rest position in response to an acceleration
having a component in the direction of double ended arrow

14. Movement of the element 11 is sensed as by the
differential capacitors including plates 15, 16 and a
plate (not shown) on displaceable element 11. A restoring
force is applied to the displaceable element by a current
05   flow through coils 17, 18. The generation of restoring
current will be described below. Further details of such
an accelerometer may be found in Jacobs U.S. patent
3,702,073.

        A detector circuit 20 connected with capacitor
10   plates 15, 16 has an analog output signal with a polarity
which indicates the direction of displacement of element
11 and an amplitude which represents the magnitude of the
displacement or other sensed stimulus. The detector
output signal is connected with the input of an up-down
15   accumulator 21 which increments for one polarity of
detector output signal and decrements for the other
polarity of detector output signal. An amplifier 22 may
be connected between detector 20 and accumulator 21 to
scale the analog signal, provide isolation between the
20   detector and the accumulator and to provide frequency
compensation should that be desirable.

        Up-down accumulator 21 as shown in the drawing has a
16 bit output which provides a binary digital output
representing the stimulus acting on the displaceable
25   element 11. The accumulator output is nominally one-half
full count for a null condition of the displaceable
element 11, e.g., the absence of an acceleration. The
binary digital output may be buffered to provide the
appropriate signal amplitude and isolation. The buffer
30   output is typically connected with a computer or other
digital signal processing equipment.

        The output of up-down accumulator 21 is also
connected with the input of a bipolar digital-to-analog
converter 25 which has a zero output for a half count of
35 . the 16 input bits. The analog output of digital-to-analog
converter 25 is connected with forcer coils 17, 18 to
return displaceable element to a null position.

Appropriate clock inputs are provided to the accumulator
21 and digital-to-analog converter 25. Amplifier 26 may
be connected between the output of digital-to-analog
converter 25 and forcer coils 17, 18 to scale the current
05   to the coils and provide frequency compensation.

When accelerometer 10 senses acceleration, the ana-
log output of detector 20 causes accumulator 21 to count
up or down. The digital-to-analog converter 25 develops
an analog rebalance current which returns the displaceable
10   element 11 to its null position.

Accumulator 21 has a low noise output which is
directly compatible with a digital computer. Null or zero
input bias errors can be compensated in the buffer circuit
by incorporating an add or subtract count circuit. As the
15   instrument is designed to interface with a digital
computer, this bias correction can also be provided by
adding or subtracting counts in subsequent processing.

During temperature and acceleration modeling, errors
of the detector, accumulator and converter can be
20   modeled along with temperature and acceleration errors of
the accelerometer 10. A composite correction is
programmed for the computer with which the accelerometer
is used.

The rebalance current typically required will be
25   between counts of the accumulator and steps of the
digital-to-analog converter 25. The 16 bit accumulator
shown in the drawing provides a 16 bit output resolution
which is approximately 1/4 mG in a 20G full range
accelerometer. The two least significant bits of the
30   binary digital output may be suppressed to avoid
instability in the digital output, or the readings may be
sampled and averaged to increase resolution beyond the
nominal 16 35 bits. Since the servo loop forces the
detector output to average zero over time, the LSB will be
35   duty cycled to average proportionately between steps. As
an additional advantage, the accumulator and digital-to-
analog converter outputs will rattle or switch back and

forth the least significant bits. This does not affect
the binary digital output. It has a beneficial effect
with an instrument having a pivot and jewel mount rather
than hinge shown in the drawing, in causing the
05   displaceable element to dither about the null position.
This reduces hysteresis and nonrepeatability errors.

Aliasing is an error which occurs when an instrument
is read by a computer. Output changes are apparent to the
computer only at transitions of the computer's clock.
10   Normally the output of the instrument will change at some
time other than the computer clock transition. If the
time to a negative going output change of the instrument
is 10.5 computer clock cycles, the time will appear to the
computer as 10 clock cycles. If the time to the next
15   positive going change is also 10.5 clock cycles it will
appear to the computer as 11 clock cycles. If changes
continue at this rate (some fraction of the computer clock
rate) this gives an error in the apparent average output
the computer sees.
20   This instrument may be syncronized with a system
clock so that output transitions can occur only after an
integer number of computer clock cycles. This eliminates
aliasing and does not increase the average error, since if
one transition is delayed, the error is stored as failure
25   to totally rebalance the pendulum and some subsequent
transition of this same polarity will occur sooner.

-6-

CLAIMS

1. A servoed instrument with a digital output, comprising:

an element displaceable in either of two opposite
05 directions from a null position in response to a sensed
stimulus;

means for applying a force to said element to return
the element to said null position;

a detector responsive to displacement of said
10 element from said null postition, having an analog output
signal with a polarity which indicates the direction of
displacement of said element from said null position and
an amplitude which represents the magnitude of the sensed
stimulus;

15 an analog-to-digital converter responsive to the
detector output signal, having a digital output
representing the sensed stimulus to which said element
responds; and

a digital-to-analog converter having an input
20 connected with the output of said analog-to-digital
converter and an analog output connected with the means
for applying a force to said element.

2. The instrument of claim 1 in which said analog-
to-digital converter is an accumulator responsive to the
detector output signal, having a binary digital output
representing the sensed stimulus to which said element
05 responds.

3. The instrument of claim 2 in which said accumu-
lator is a counter which counts up for one polarity of
detector output signal and counts down for the opposite
polarity of detector output signal.

4. The instrument of claim 3 in which the output of said accumulator is one-half full count for a null condition in the absence of a stimulus acting on said displaceable element.

5. The instrument of claim 1 including an amplifier connected between said detector and said analog-to-digital converter.

6. The instrument of claim 5 in which said amplifier provides frequency compensation for the analog output signal from the detector.

7. The instrument of claim 1 in which said analog-to-digital converter has an n-bit output with the m most significant bits providing a digital measure of the sensed stimulus and the (n-m) least significant bits effecting dithering of the displaceable element.

8. The instrument of claim 1 including a buffer circuit connected with the output of the analog-to-digital converter for deriving a binary digital representation of the sensed stimulus therefrom.

9. The instrument of claim 8 in which said buffer circuit compensates the digital output signal for bias in the output of the instrument with a null condition of the sensed stimulus.

10. The instrument of claim 1 in which said digital-to-analog converter has a bipolar analog output.

11. The instrument of claim 10 in which said digital-to-analog converter has a zero analog output for one-half full scale digital input.

-9-

12.   The instrument of claim 1 including an ampli-
fier connected between the digital-to-analog converter and
the force applying means.

13.   The instrument of claim 10 including an ampli-
fier connected between the digital-to-analog converter and
the force applying means.

14.   The instrument of claim 12 in which said
amplifier provides frequency compensation for the analog
output signal from the digital-to-analog converter.

15.   The instrument of claim 13 in which said
amplifier provides frequency compensation for the analog
output signal from the digital-to-analog converter.

16.   A servoed instrument with a binary digital
output, comprising:
         means for applying a force to said element to return
the element to said null position;
05   a detector responsive to displacement of said
element from said null position, having an analog output
signal with a polarity which indicates the direction of
displacement of said element from said null position and
an amplitude which represents the magnitude of the sensed
10   stimulus;
         an accumulator responsive to the detector output
signal, having a binary digital output representing the
sensed stimulus to which said element responds, said
accumulator incrementing for one polarity of output signal
15   and decrementing for the opposite polarity of output
signal and the output of said accumulator being one-half
full count in the absence of a stimulus acting on said
displaceable element; and
         a digital to analog converter having an input
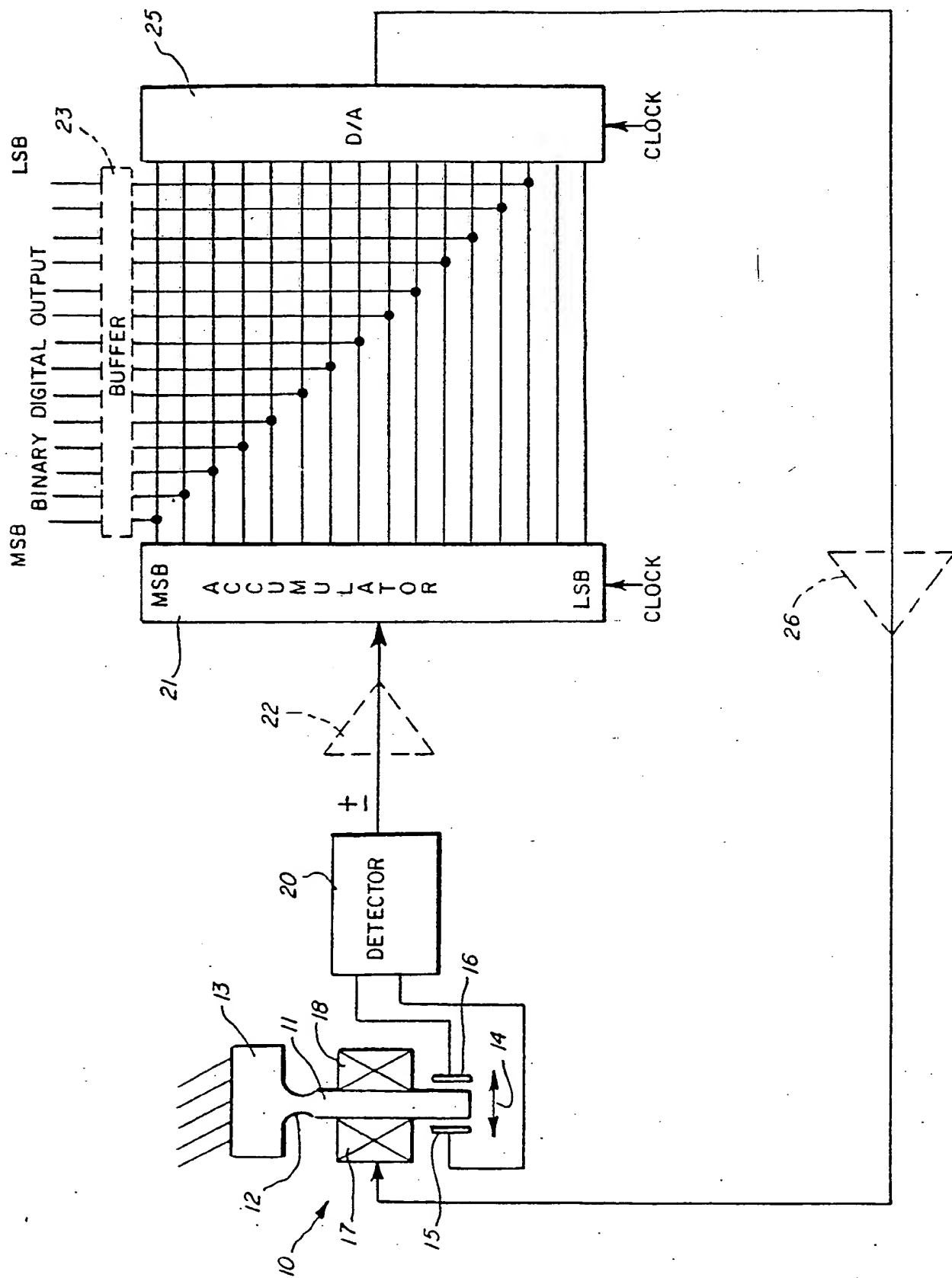20   connected with the output of said analog-to-digital

converter and a bipolar analog output connected with the
means for applying a force to said element, one-half full
scale digital input corresponding with a zero analog
output from said digital-to-analog converter.

17.   In a servoed accelerometer having a mass
movable in opposite directions from a null position in
response to accelerations and means for applying a
rebalance force to the mass, a digital output circuit
05   comprising:
a detector responsive to displacement of said mass
from said null position having an analog output signal
with a polarity which indicates the direction of the
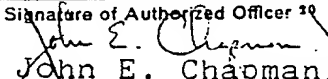acceleration and an amplitude which represents the
10   intensity thereof;
an analog-to-digital converter responsive to the
analog detector output signal having a digital output
representing the sensed acceleration; and
a digital-to-analog converter having an input
15   connected with the output of said analog-to-digital
converter and an analog output connected with the means
for applying a restoring force to the mass.

INTERNATIONAL SEARCH REPORT

International Application No **PCT/US85/01143**

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 3

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.³ G01P 15/13

U.S. CL. 73/ 517B; 318/648,651

II. FIELDS SEARCHED

Minimum Documentation Searched 4

Classification System	Classification Symbols
U.S.	73/517B 318/601, 648,651

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 5

III. DOCUMENTS CONSIDERED TO BE RELEVANT 14

Category *	Citation of Document, 16 with indication, where appropriate, of the relevant passages 17	Relevant to Claim No. 18
X,Y	US,A, 3,081,637, 19 March 1963, Gevas.	1-17
X,Y	US,A, 3,192,371, 29 June 1965, See Figure 4, Brahm.	1-17
X,Y	US,A, 4,282,470, 04 August 1981, Reynolds.	1-17
Y	US,A, 3,618,401, 09 November 1971, Lacey.	5,12-13
Y	US,A, 3,508,254, 21 April 1970, Ross et al.	7
Y	US,A, 4,315,434, 16 February 1982, Eastman.	7
Y	US,A, 3,545,284, 08 December 1970, Clement et al.	4,11 and 16

* Special categories of cited documents: 15

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 3	Date of Mailing of this International Search Report 3
15 July 1985	**23 JUL 1985**
International Searching Authority 1	Signature of Authorized Officer 20
ISA/US	John E. Chapman, Jr.

Form PCT/ISA/210 (second sheet) (October 1981)